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Phosphorus Removal Study at the Sarnia WPCP

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PHOSPHORUS REMOVAL STUDY

AT THE SARNIA WPCP

by

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RESEARCH PROGRAM FOR THE ABATEMENT
OF MUNICIPAL POLLUTION WITHIN THE
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ABSTRACT

This research project was conducted by staff of the Research Branch of the Ministry of the Environment at the Sarnia WPCP from January to June, 1972 to investigate:

(1) The effects of ferric chloride dosage, mixing and hydraulics on the removal of total phosphorus in a primary wastewater treatment plant.

(2) The effects of ferric chloride addition for phosphorus removal on the anaerobic sludge digestion process.

This programme was established immediately following a jar test study and a temporary full scale phosphorus study using ferric chloride, which had earlier been conducted by the Dow Chemical Company of Canada, Ltd.

This report describes the existing facilities at the Sarnia WPCP, and presents the average process and analytical data obtained from November, 1971 to June, 1972. The effects of various dosages of ferric chloride, with and without the addition of polymers, under various mixing and primary clarifier hydraulic conditions are discussed with respect to phosphorus removal and other effluent quality parameters. Similarly, the effects of the chemical addition on sludge production and anaerobic sludge digestion are presented.

The report concludes that the addition of 20 mg/l Fe^{+++} as ferric chloride to the pre-aeration or grit tanks will reduce the primary effluent total phosphorus concentration to less than 1 mg/l, while maintaining an acceptable effluent with respect to the BOD and suspended solids concentrations at upflow rates of less than 900 gal/sq ft/day (44.1 cu m/sq m/day). Tests conducted at higher upflow rates were inconclusive and additional work is recommended. The report further concludes that the addition of ferric chloride did not adversely affect the anaerobic sludge digestion process nor was phosphorus released from the sludge during the process.

RÉSUMÉ

Le personnel de la Direction de la recherche, du ministère ontarien de l'Environnement, a réalisé ce projet de recherche à l'usine d'épuration d'eau de Sarnia, au cours des mois de janvier à juin 1972, en vue de déterminer:

(1) l'action des différentes concentrations, du mélange et des propriétés hydrauliques de chlorure de fer (III) sur l'élimination du phosphore total dans une usine d'épuration primaire des eaux résiduaires; et

(2) l'action de l'addition de chlorure de fer (III) sur l'élimination du phosphore dans le procédé de digestion anaérobie des boues.

On a décidé du programme à suivre immédiatement après une étude en laboratoire et une étude temporaire à échelle normale du phosphore à l'aide du chlorure de fer (III), qui avaient été faites par la Cie Dow Chemical Company of Canada, Ltd.

Le présent rapport décrit les installations de l'usine d'épuration d'eau de Sarnia et expose la méthode générale suivie et les données analytiques obtenues de novembre 1971 à juin 1972. On y discute de l'action des différentes concentrations en chlorure de fer (III), avec ou sans addition de polymères, et à différents régimes hydrauliques prévalant lors du mélange et dans le clarificateur primaire, par rapport à l'élimination du phosphore et aux autres paramètres de qualité. De même, ou y expose l'action de l'addition de produits chimiques sur la production des boues et sur la digestion anaérobie de celles-ci.

Le rapport termine en disant que l'addition de 20 mg/l de Fe^{+++} sous forme de chlorure de fer (III) dans les réservoirs d'aération préliminaire ou de dessablement réduit la concentration en phosphore total de l'effluent primaire à moins de 1 mg/l, tout en y conservant un niveau de DBO et une concentration en matières en suspension acceptables, pour des débits à circulation ascendante de moins de 900 gal/pi^2/jour (44.1 m^3/m^2/jour). Les essais faits à plus grands débits ascendants n'ont pas été concluants et on recommande d'y consacrer des travaux supplémentaires. Enfin, le rapport conclut en disant que l'ad-

dition de chlorure de fer (III) n'a pas nui au processus de la digestion anaérobie des boues et qu'il n'y a pas eu de libération du phosphore par les boues au cours de l'application de ce procédé.

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1. INTRODUCTION

A research project was conducted at the Sarnia WPCP by staff of the Research Branch of the Ministry of the Environment from January to June, 1972. This project, to investigate the chemical removal of phosphorus from raw sewage in a primary waste treatment plant with sludge digestion, was undertaken as a portion of the overall study into the chemical removal of phosphorus funded under provisions of the Canada-Ontario Agreement on the Lower Great Lakes.

Earlier tests conducted by the Dow Chemical Company of Canada Ltd., from September to December, 1971, had established that ferric chloride at a dosage of 20 mg/l Fe^{+++} could produce an effluent containing less than 1 mg/l total phosphorus.

This study commenced in January, 1972 using ferric chloride as the prime coagulant for phosphorus removal, and was designed to ascertain how phosphorus removal and effluent quality would be affected by the following:

i) variations in primary clarifier hydraulic loadings;
ii) variations in dosage rates of ferric chloride;
iii) the addition of a coagulant aid;
iv) changes in the point of chemical addition and mixing conditions.

A further major consideration was the effect of ferric chloride on sludge production and on the anaerobic digestion process.

2. DESCRIPTION OF PLANT

The Sarnia WPCP is a primary waste treatment plant with anaerobic sludge digestion designed for a dry weather flow of 8.0 mgd (36,400 cu m/day). The raw sewage passes through mechanically cleaned bar screens and two Parshall flumes prior to entering the wet wells. Flow control is achieved by manually varying pump speeds relative to the wet well liquid levels. The two variable speed raw sewage pumps are each rated at 3.0 mgd to 12.0 mgd (13,600 cu m/day to 54,600 cu m/day) and gas engine driven. A further two pumps are each rated at 10 mgd (45,500 cu m/day) and are electrically driven. The raw sewage is then divided into two aerated grit tanks each with a capacity of 11,800 cu ft (334 cu m), followed by two pre-aeration tanks each with a capacity of 33,700 cu ft (954 cu m) and providing approximately twenty minutes detention time at design flow. The four rectangular primary clarifiers each have a capacity of 36,500 cu ft (1034 cu m), a weir length of 162 ft (49.4 m) and an upflow rate at design flow of 490 gal/sq ft/day (24 cu m/sq m/day), corresponding to a 2.75 hour retention time.

The two stage anaerobic digestion system comprises two 60 ft (18.3 m) diameter primary digesters having a combined liquid capacity of 141,000 cu ft (3,993 cu m) and a 60 ft (18.3 m) diameter secondary digester with a liquid capacity of 65,000 cu ft (1841 cu m). The primary digesters are installed with a gas recirculation mixing system, and are heated by one spiral fin heat exchanger with a capacity of 1.25×10^6 Btu/hr (1.32 G.J./h). Digested sludge is pumped to sludge lagoons occupying approximately 35 acres (14.6 hectares), one to three times per week. Digester gas is utilized for heating the control building, the primary digester heat exchanger and as fuel for the gas engine driven pumps. Excess gas is vented to a waste gas burner. No functional gas metering equipment was available at the time of the study.

The plant is supervised 24 hours per day and has its own laboratory facilities.

3. DESCRIPTION OF STUDIES

Table 1 is a chronological summary of studies conducted indicating the dosages of chemicals used, the average daily flows, the number of primary clarifiers and the resultant upflow rates, and the points of application, for the period September 29, 1971 to June 11, 1972. Data listed from September 29, 1971 to December 26, 1971 were obtained by the Dow Chemical Company of Canada, Ltd. (1972).

In order to simplify discussion of the numerous operating conditions investigated, the programme has been divided into Stages 1 to 14. All samples of raw sewage and primary effluent were daily composites of hourly grab samples over a 24-hour period.

Raw sludge and digester sludge samples were obtained by grab sampling. Frequency of sampling was either daily or on alternate days. All analyses were conducted using the Sarnia WPCP laboratory facilities.

The ferric chloride and polymer dosing rates were adjusted manually in proportion to the incoming raw sewage flow, on an hourly basis 24 hours per day. The ferric chloride was added to the inlet end of the pre-aeration tank using the cross roll effect for mixing, or at the inlet of the grit chamber where a submerged 4 ft (1.22 m) diameter inlet pipe and distribution baffle resulted in a violent mixing condition. The polymer, Purifloc A23, was added at the outlet of the pre-aeration tank via a trough running the length of the outlet channel and was diluted with water for maximum distribution.

Ferric chloride addition was to the inlet end of the pre-aeration tanks; Fe^{+++} dosages marked † in Table 1 indicate that the point of addition was changed to the grit chambers.

TABLE 1

SUMMARY OF TEST CONDITIONS

Dates Start	Finish	Stage Number	Clarifiers in Service	Fe^{+++} mg/l	Purifloc A23 mg/l	Flow Data Max. mgd*	Min. mgd*	Avg. mgd*	Clarifier Loading gal/sq ft/ day**
Sept.29-	Oct.16/71	1	3	15	0.3	7.65	5.95	6.66	548
Oct.17-	Nov.2/71	2	3	15	0.5	8.08	5.74	6.73	554
Nov.3-	8/71	3	3	20	0.5	6.45	5.72	6.20	510
Nov.9-	20/71	4	3	10	0.3	6.99	5.63	6.51	536
Nov.21-	Dec.1/71	5	3	15	Nil	8.86	6.19	6.86	564
Dec.2-	13/71	6	3	20	Nil	8.71	6.02	6.96	573
Dec.18-	26/71	7	3	20	0.3	8.11	6.48	7.20	593
Jan.4-	16/72	8	3	17	0.3	8.23	6.83	7.38	607
Jan.18-	Feb.10/72	9	3	17	Nil	8.39	6.23	7.34	604
Feb.13-	Mar.5/72	10	2	17	Nil	7.93	5.99	6.76	834
Mar.6-	8/72	11	1	17	Nil	-	-	8.48	2090
Apr.2-	18/72	12 a)	2 (2:1 flow split)	17	0.3	7.93	6.28	7.54	1234
		b)							617
Apr.30-	May 22/72	13	3	9†	Nil	8.96	6.20	7.40	609
May 25-	June 11/72	14	2	17†	Nil	8.88	6.22	7.45	919

* x 4.546 = 10^3 cu m/day

** x 0.049 = cu m/sq m/day

4. ANALYTICAL RESULTS

The average analytical data for each stage for raw sewage and primary effluent characteristics are presented in Table 2. Raw pH values ranged from 6.9 to 7.4. Primary effluent pH values were depressed by about 0.1 unit because of the addition of ferric chloride.

The raw, primary, and digested sludge data are presented in Table 3. Since no significant differences in these data were observed or expected from stage to stage, the data presented are an average obtained from samples taken on alternate days during the period January 4, 1972 to July 2, 1972.

TABLE 2

RAW SEWAGE AND PRIMARY EFFLUENT ANALYTICAL DATA

Stage No.	RAW SEWAGE BOD mg/1	SS mg/1	TOTAL P mg/1	ORTHO P mg/1	PRIMARY EFFLUENT BOD mg/1	SS mg/1	TOTAL P mg/1	ORTHO P mg/1
1	110	114	5.7	3.2	38	16	1.30	0.78
2	105	148	5.9	3.1	34	26	1.33	0.67
3	99	82	6.6	3.0	33	17	0.79	0.20
4	104	132	6.3	2.8	41	16	2.33	1.09
5	100	119	5.3	2.7	39	33	1.18	0.52
6	98	117	5.0	2.5	37	28	0.74	0.14
7	91	138	5.2	2.2	33	22	0.69	0.25
8	81	116	3.8	2.1	34	22	0.50	0.30
9	89	109	6.2	2.4	37	30	0.94	0.45
10	115	125	6.4	3.0	50	28	1.40	0.70
11	81	216	4.8	2.1	-	508	-	-
12 a)	91	102	6.0	2.2	45	32	1.50	0.47
b)	91	102	6.0	2.2	44	14	0.80	0.32
13	86	109	5.9	2.3	37	28	1.67	0.73
14	111	212	6.6	2.6	33	31	1.10	0.24

TABLE 3

RAW SLUDGE AND DIGESTER DATA

Analysis	Raw Sludge	Primary Digester	Digested Sludge	Supernatant
% Solids	4.3	4.8	16.0	0.17
% Volatile Solids	54.5	41.7	39.4	-
Volume	26,800 gpd (122 cu m/day)			
pH Range	6.6-7.1	6.9-7.4	6.9-7.2	6.8-7.0
Volatile Solids	6,360 lb/day (2,885 kg/day)	-	-	-
% VS Reduction	-	41	45	-
Total P	1,120 mg/l	-	3,000 mg/l	30 mg/l
Ortho P	1.0 mg/l	-	1.9 mg/l	0.5 mg/l
Volatile Acid	-	412 mg/l	-	-
Fe^{+++}	3,860 mg/l	-	11,000 mg/l	230 mg/l

5. DISCUSSION OF RESULTS

5.1 The effect of Variations in Fe^{+++} Concentrations

Primary effluent total phosphorus data obtained at clarifier upflow rates ranging between 500 and 800 gal/sq ft/day (24.5 and 39.2 cu m/sq m/day) were analyzed at Fe^{+++} dosages of 8.8 mg/l, 15 mg/l and 20 mg/l. These data are presented versus probability in Figure 1. The graph indicates that an effluent containing less than 1 mg/l total phosphorus can be achieved for up to 80 per cent of the time only at 20 mg/l Fe^{+++} dosages. Lower Fe^{+++} dosages resulted in an increase in the effluent total phosphorus concentrations. The average analytical data in Table 2 (stages 5, 6, 9, and 13) indicate that primary effluent suspended solids concentrations at the dosages studied were virtually the same, indicating that variations in the total phosphorus concentration were not related to the suspended solids.

Comparing variations in ferric dosage with the soluble orthophosphorus content of the primary effluent, (Figure 2), it can be seen that as the ferric dosage decreased, the orthophosphorus concentrations increased. It is this effect which appears to account for the high total phosphorus concentrations demonstrated in Figure 1. The lower line in Figure 2 shows the decreased orthophosphorus concentrations as the result of increased mixing. (Refer to Section 5.4)

5.2 Effects of 0.3 mg/l Purifloc A23 on Phosphorus Removal

In order to determine the effect of the addition of 0.3 mg/l Purifloc A23 as a coagulant aid to 17 mg/l Fe^{+++}, tests with and without the polymer were conducted at upflow rates in the range of 500 to 800 gal/sq ft/day (24.5 to 39.2 cu m/sq m/day). Total phosphorus and suspended solids concentrations in the primary effluent are plotted against probability in Figures 3 and 4. It can be seen from Figure 3 that the addition of polymer resulted in a 25 per cent reduction in primary effluent total phosphorus, and that data on Figure 4 suggest that this can be related directly to improved suspended solids removals. Table 2 (stages 8, 9, and 12b) indicates that only a slight difference in orthophosphate occurred and, therefore, it is unlikely that the polymer

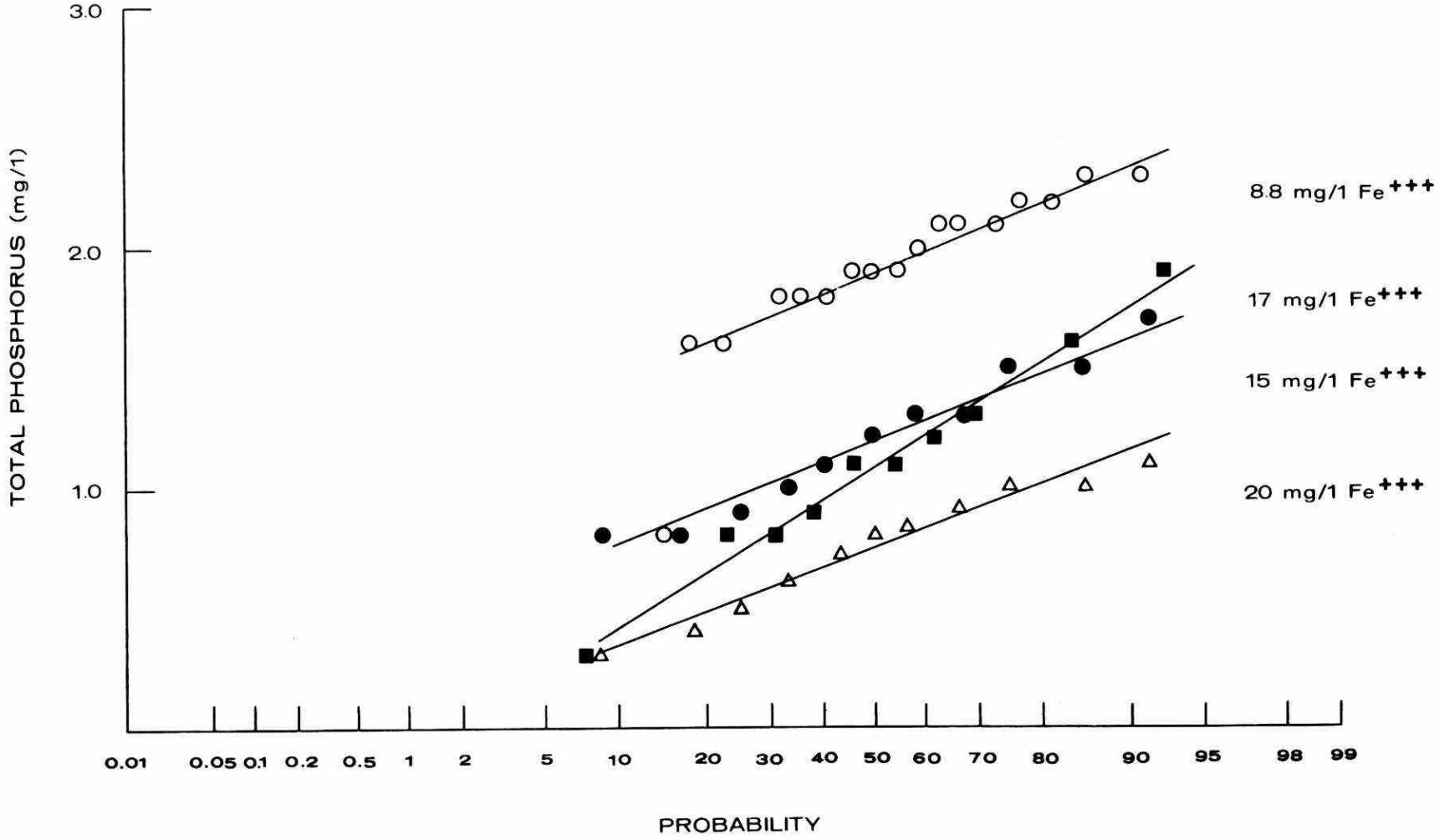

Figure 1: Effects of Fe^{+++} Dosage on Primary Effluent Total Phosphorus at Upflow Rates of 500-800 gal/sq ft/day (24.5-39.2 cu m/sq m/day).

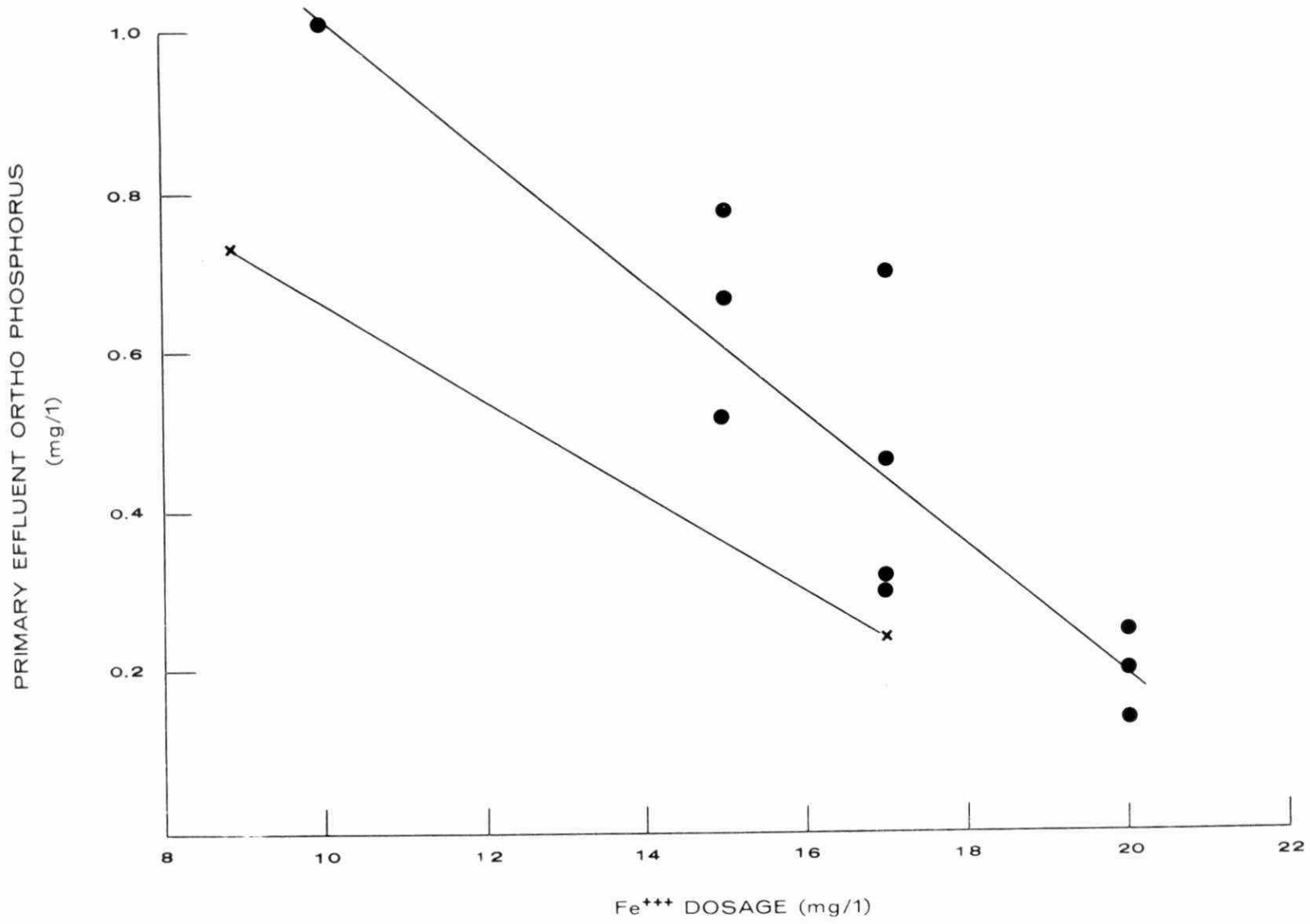

Figure 2: Fe^{+++} Dosage Vs. Primary Effluent Ortho Phosphorus.

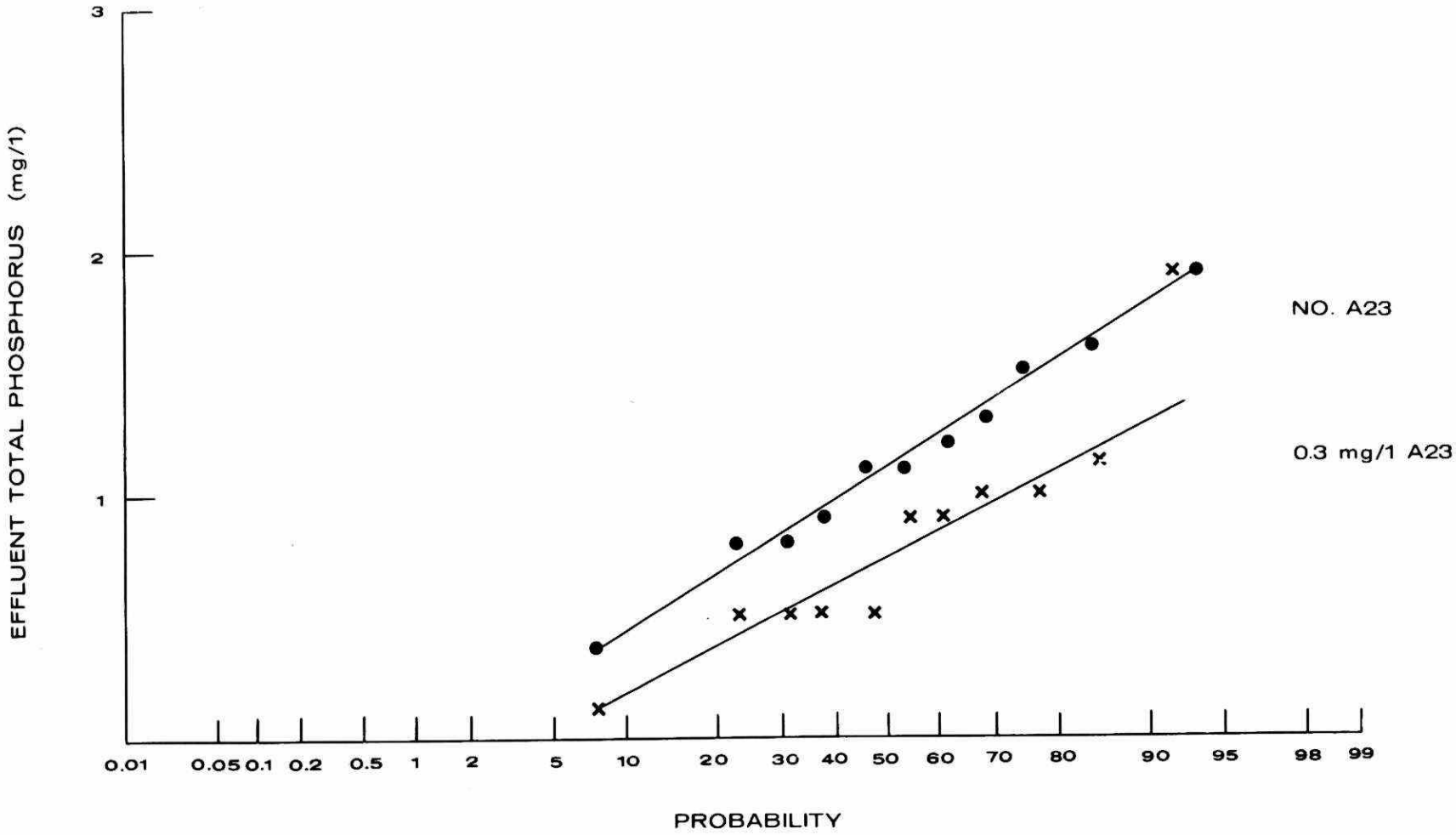

Figure 3: Effects of 17 mg/1 Fe^{+++} With and Without 0.3 mg/1 A23 On Primary Effluent Total Phosphorus.

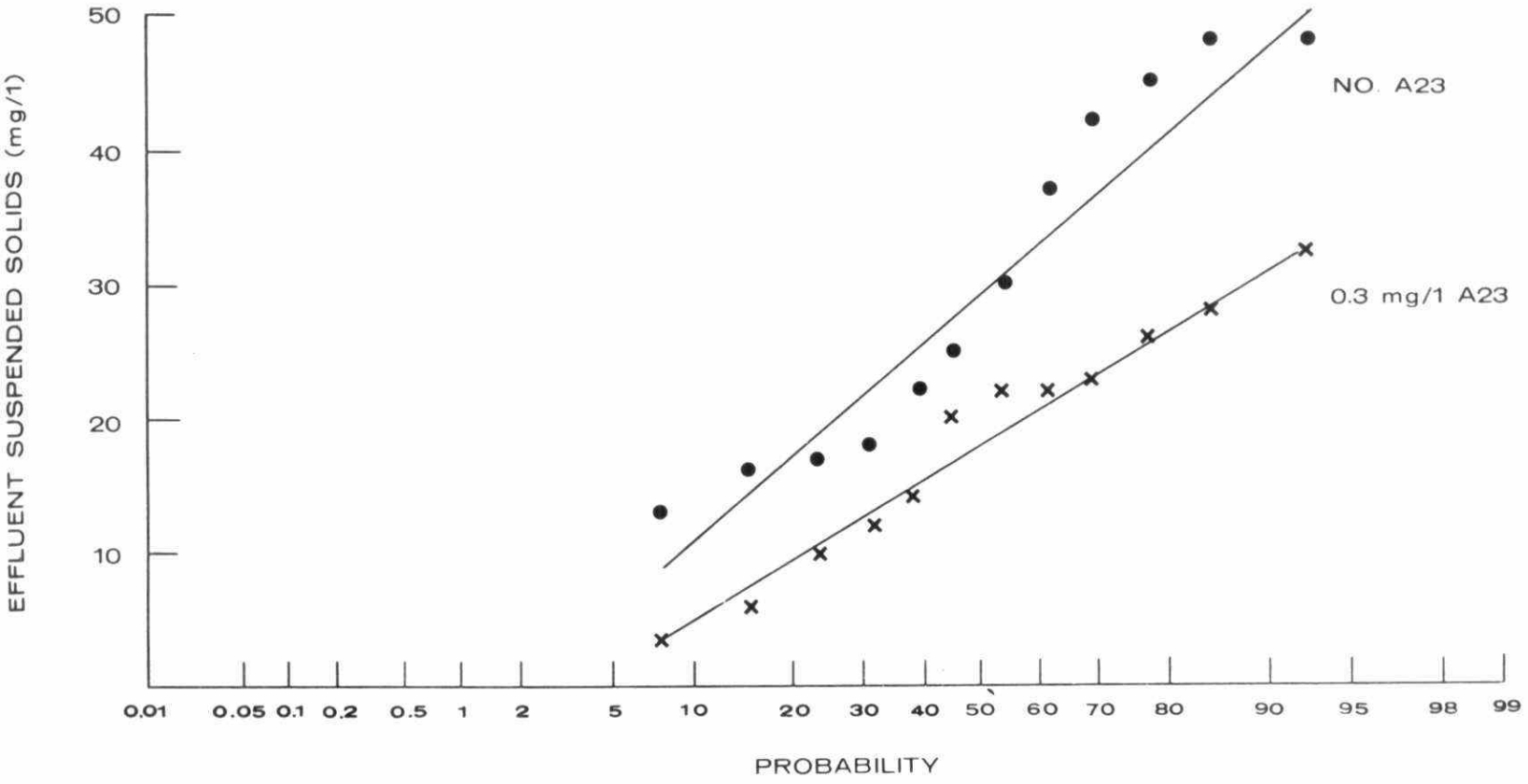

Figure 4: Effects of 17 mg/1 Fe^{+++} With and Without 0.3 mg/1 A23 on Primary Effluent Suspended Solids

directly effected phosphorus removal, but rather, enhanced suspended solids removal.

It is interesting to note that effluent quality with respect to total phosphorus, using 17 mg/l Fe^{+++} and 0.3 mg/l A23, was almost identical to the data obtained using 20 mg/l Fe^{+++} as shown in Figure 1. It seems, therefore, that 0.3 mg/l A23 was equivalent in increased performance, to 3 mg/l Fe^{+++} in this installation.

Comparing the costs of the two chemicals per million gallons (10^3cu m) of sewage treated:

0.3 mg/l A23 - \$5.00/mg @ \$1.70/lb, (\$3.75/kg)

3 mg/l Fe^{+++} as $FeCl_3$ - \$2.20/mg @ .67/lb, (\$1.47/kg)

5.3 The Effect of Variations in Primary Clarifier Hydraulics

The effects of primary clarifier upflow rates on effluent quality were investigated at an Fe^{+++} dosage of 17 mg/l. Upflow rates were controlled over a range from 500 to 2000 gal/sq ft/day (24.5 to 98 cu m/sq m/day). As can be seen from the relevant data in Table 2 (stages 9, 10, 11 and 14), effluent quality with respect to BOD, suspended solids and total phosphorus did not vary substantially over a range of upflow rates up to 920 gal/sq ft/day (45.1 cu m/sq m/day). Consistent effluent quality at upflow rates over the range of 920 gal/sq ft/day (45.1 cu m/sq m/day) to 1250 gal/sq ft/day (61.2 cu m/sq m/day) could not be attained. Additional work is recommended in this area. At an upflow rate of 2090 gal/sq ft/day (102.4 cu m/sq m/day), an excessive carry-over of solids occurred with a suspended solids concentration of 509 mg/l. The physical design of the plant, raw sewage flow, and the duration of the study did not permit tests between 1250 gal/sq ft/day (61.2 cu m/sq m/day) and 2090 gal/sq ft/day (102.4 cu m/sq m/day). In Figure 5, primary effluent suspended solids concentrations are compared with clarifier upflow rates. It is apparent over the range of data shown that no conclusive relationship exists, possibly the result of the analytical data being from 24 hour composite samples, and the upflow rates being calculated from the daily average flow.

Primary clarifier turbidity measurements were recorded throughout the study using a Hach surface scatter turbidity meter. As a result

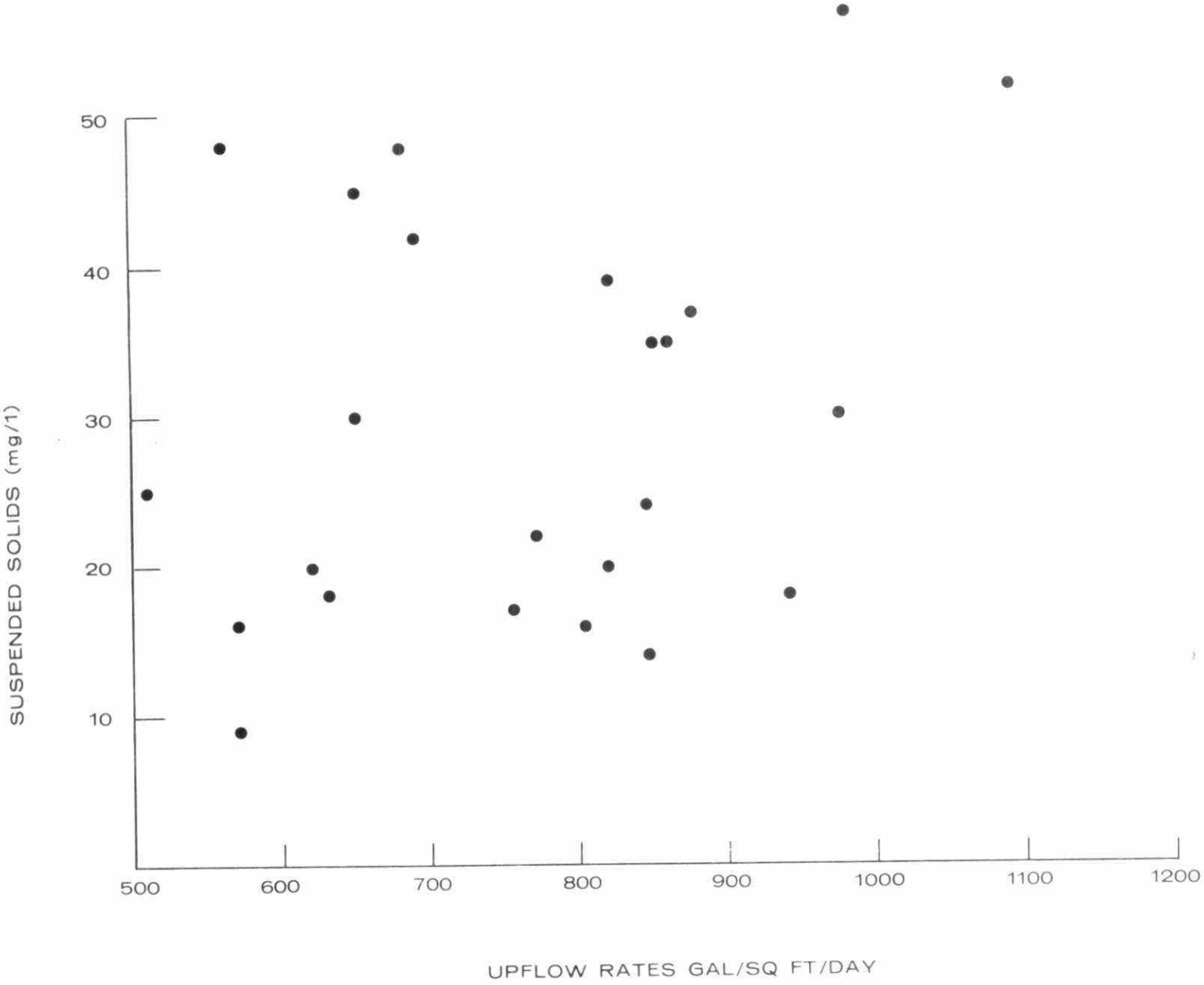

Figure 5: Primary Effluent Suspended Solids Vs. Upflow Rate

Fe^{+++} - 17 mg/1.

of the manual control of the raw sewage pumps, flow conditions during the day were often steady for periods of three to five hours. The data presented in Figure 6 were obtained from turbidity readings taken during these steady flow conditions. The graph indicates a steady increase in turbidity as the upflow rates increased, with a significant change occurring over 1100 gal/sq ft/day (53.9 cu m/day). The suspended solids concentrations on the right of Figure 6 are actual solids obtained from grab samples at the turbidity readings indicated and demonstrate that a linear relationship between suspended solids and turbidity did not exist in this case.

5.4 The Effect of Mixing at the Point of Fe^{+++} Addition

A limited study was conducted to compare mixing conditions at the point of ferric chloride addition on effluent total phosphorus concentrations. In the earlier stages of the programme, the ferric chloride was added to the inlet end of the pre-aeration tank using the roll effect as the mixing agent. In later stages (Table 1, stages 13 and 14) the ferric chloride was added at the submerged inlet to the grit tanks. At this point, the incoming sewage flowed through a four foot (1.22 meters) diameter inlet pipe striking a distribution baffle located two feet (0.61 meters) from the inlet, creating violent mixing conditions. As indicated in Figure 7, the violent mixing conditions did result in increased removal of total phosphorus. Comparing the analytical results in Table 2, stages 10 and 14, it can be seen that the improvement can be related to orthophosphorus removal since the suspended solids concentration in both stages was virtually the same.

5.5 The Effect of Ferric Chloride on the Anaerobic Sludge Digestion Process

5.5.1 Raw sludge

From the limited data available, raw sludge production during 1969 averaged 20,000 gal/day (90.9 cu m/day) of 4 per cent solids concentration, which at a daily flow of 6.3 mgd (28,600 cu m/day) is equivalent to 1270 lb solids/MG (126.7 kg solids/10^3cu m). The average raw sludge data for the period of the ferric chloride study with similar raw sewage characteristics (Table 3) showed 26,800 gal/day (122 cu m/day) of 4.36

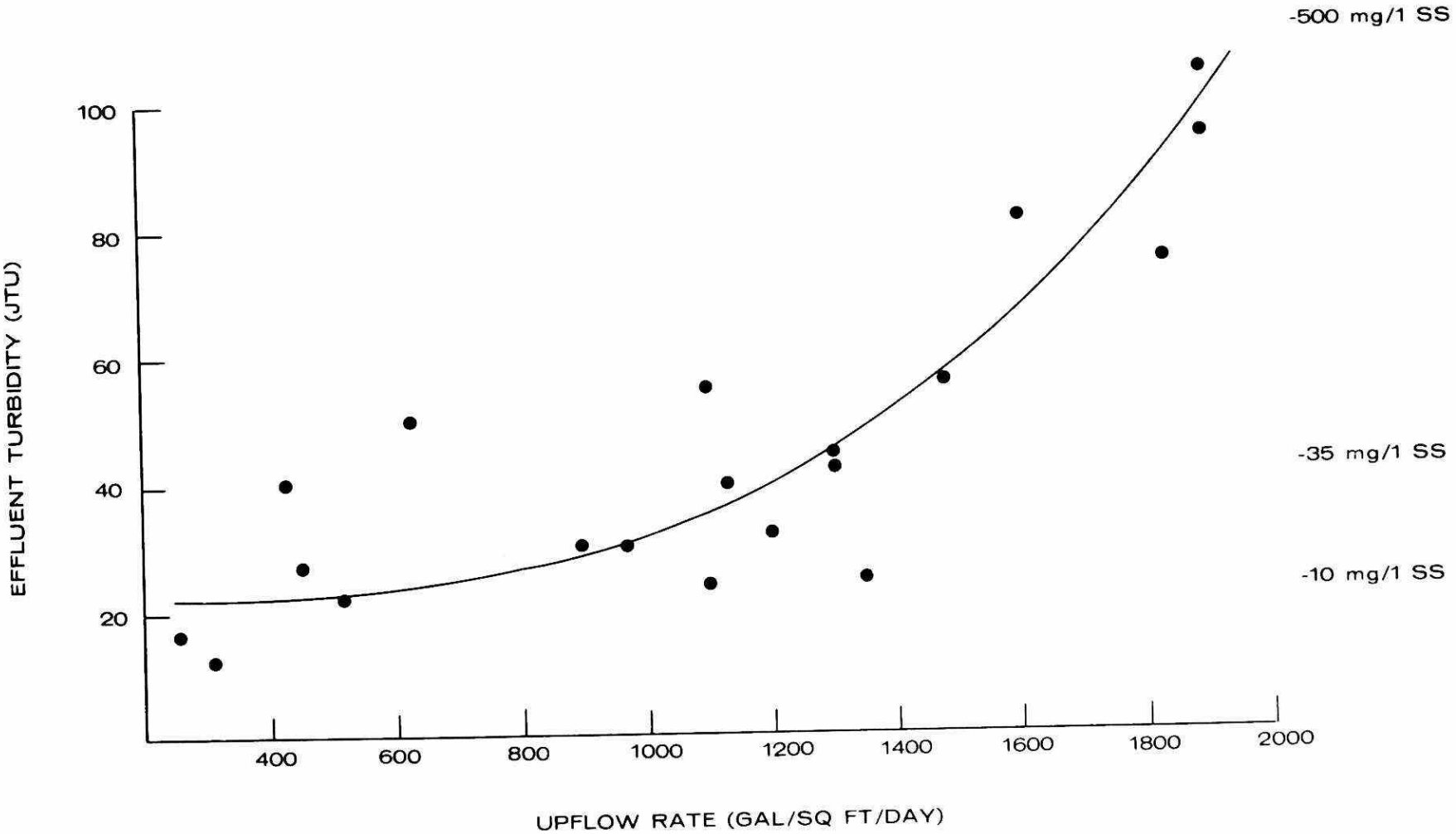

Figure 6: Primary Effluent Turbidity Vs. Upflow Rate.

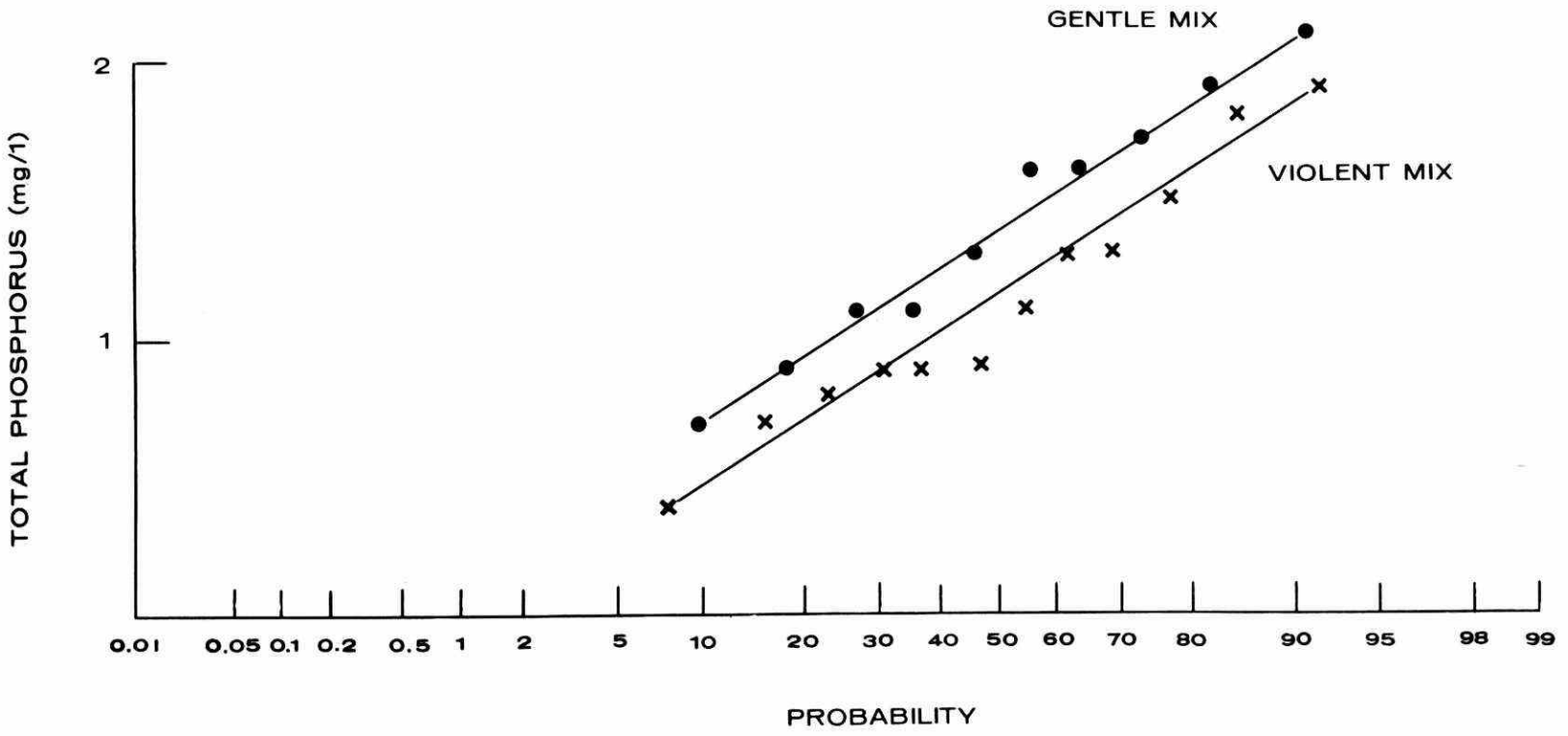

Figure 7: Effects of Mixing At the Point of Fe^{+++} Addition.

per cent solids which is equivalent to 1600 lb solids/MG (159.7 kg solids/ 10^3cu m). This represents an increased solids capture of 26 per cent as a result of chemical addition. No difference in sludge volumes or solids concentrations were apparent during the various stages of the study.

5.5.2 Primary digesters

The volatile solids loading to the primary digesters (Table 3) for the period January to July, 1972 averaged 6360 lb/day (2885 kg/day), which is equivalent to a primary digester loading of 0.04 lb VS/cu ft/day (0.64 kg VS/cu m/day). Digester gas analyses for the period averaged 68 per cent methane. Gas volumes were not determined because of meter failure; however, it is interesting to note that prior to the study, only 75 per cent of the WPCP operating fuel was supplied by the digesters. During the ferric chloride study, no auxiliary fuel supplies were necessary. Volatile acid concentrations averaged 412 mg/l and ranged between 56 mg/l and 1400 mg/l. The high volatile acid values were the result of poor mixing by the gas recirculation equipment. This poor mixing allowed sludge to settle below the inlet to the sludge recirculation pumps, which were 9 feet (2.74 meters) from the floor of the digesters. This problem may or may not have been the result of ferric chloride addition and was rectified by using the bottom sludge withdrawal port of the digester and larger pump for sludge recirculation. Temperatures were maintained between 89^{o}F and 92^{o}F and approximately 42 per cent breakdown of volatile solids was achieved in the primary digester.

5.5.3 Digested sludge

Analyses of sludge transferred to the lagoons indicated total solids ranging from 12 per cent to 18 per cent with an average of 16 per cent (Table 3). The iron and phosphorus concentration of the sludge appeared to reach equilibrium levels of 6.8 per cent and 1.9 per cent respectively on a dry weight basis. The orthophosphorus concentration of 1.9 mg/l indicates that once the phosphorus was chemically bound, the anaerobic digestion process did not cause a release.

5.5.4 Supernatant

As indicated by Table 3, no supernatant volumes were available. Suspended solids concentrations averaged 1700 mg/l, while the low ortho-

phosphorus concentrations of 0.5 mg/l again indicate that phosphorus was not released during the anaerobic sludge digestion process.

6. CONCLUSIONS

The following conclusions have been made on the basis of the results of this study:

1) Primary effluent upflow rates of less than 900 gal/sq ft/day (44.1 cu m/sq m/day) in conjunction with a Fe^{+++} dosage of 20 mg/l result in a primary effluent containing less than 1 mg/l total phosphorus. Satisfactory performance at upflow rates up to 1250 gal/sq ft/day (61.2 cu m/sq m/day) may be possible.

2) The addition of 0.3 mg/l Purifloc A23 in addition to ferric chloride improves effluent quality and marginally reduces the ferric chloride dosage required.

3) Increased mixing at the point of addition of the ferric chloride results in a 20 per cent increase in phosphorus removal.

4) The addition of Fe^{+++} for the removal of total phosphorus does not adversely affect the anaerobic sludge digestion process. However, adequate mixing of the primary digesters is essential to ensure trouble-free operation.

5) Chemically bound phosphorus is not released by the anaerobic digestion process.

7. RECOMMENDATIONS

Based on the results obtained in this study, the following recommendations are made:

1) Further work should be initiated to determine the critical upflow rate which appears to lie in the 900 to 2000 gal/sq ft/day (44.1 to 98.0 cu m/sq m/day) range for acceptable effluent quality.

2) The addition of polymer in conjunction with 20 mg/l Fe^{+++} should be investigated with respect to a possible increase in primary clarifier upflow rates while maintaining an acceptable effluent quality.

REFERENCE

1) Dow Chemical Co. of Canada Ltd., "Phosphorus Removal Trial, Sarnia Water Pollution Control Centre, Sarnia, Ontario", September 18, 1972.